

M-Wave Imaging

*Using Dual Tuned Resonant Coils to Image Metal,
Graphite Composite and Plastic*

*By Kevin McGushion
EXEL Orbital Systems, Inc*



1980 Science Fair

15 Year Old Nerd

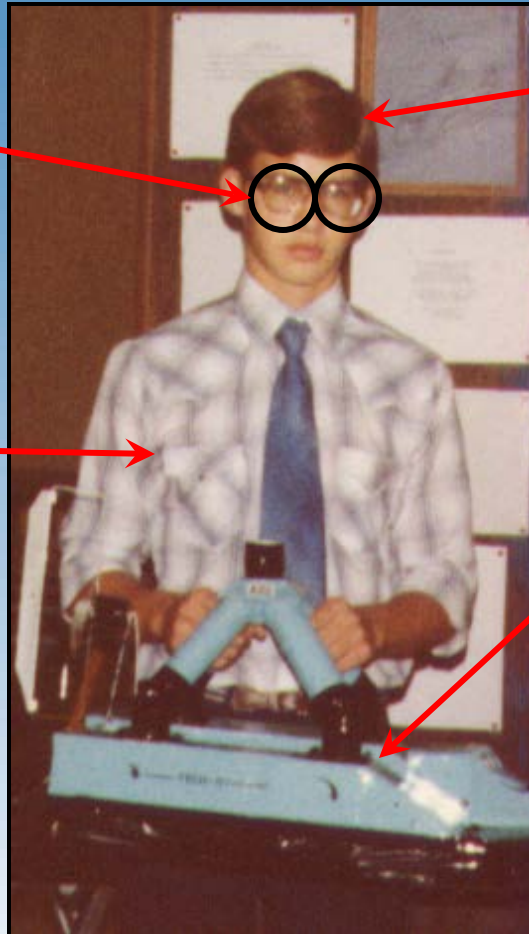
Coke Bottle
Glasses

Slightly Out of
Date Hairstyle

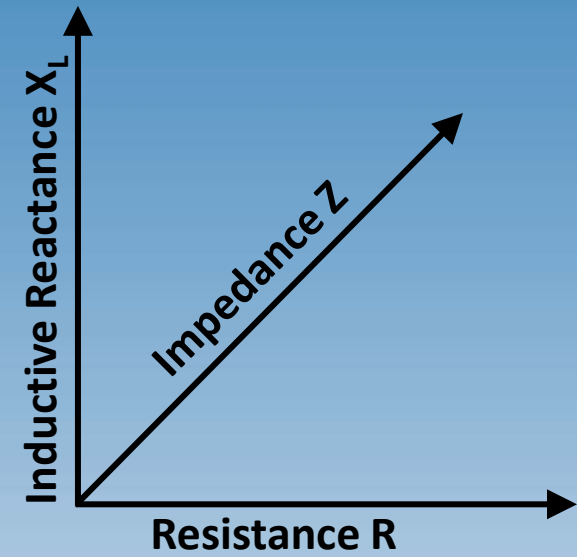
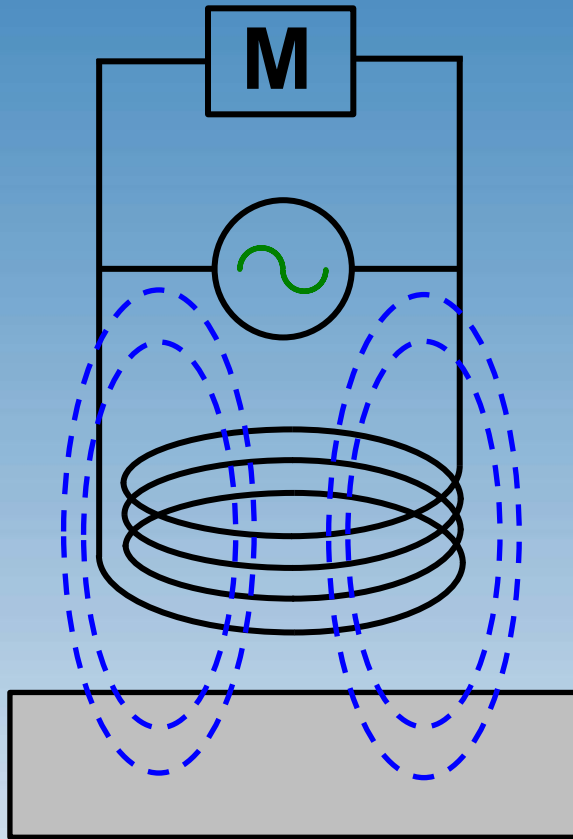
Pen in Pocket

Sadly not a
pocket
protector.

Holding My
Science Project

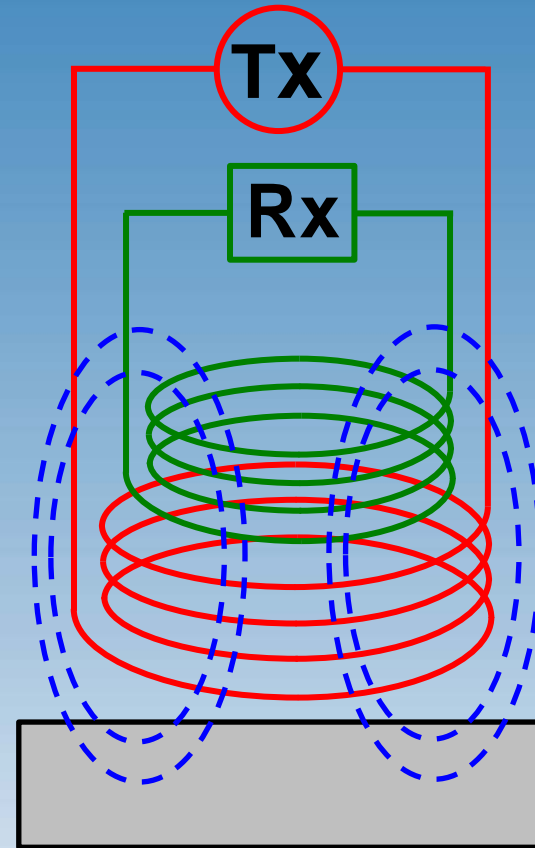
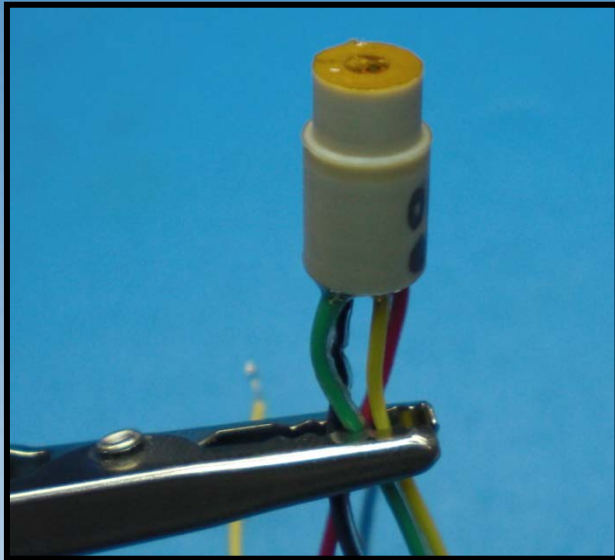


Traditional Eddy Current

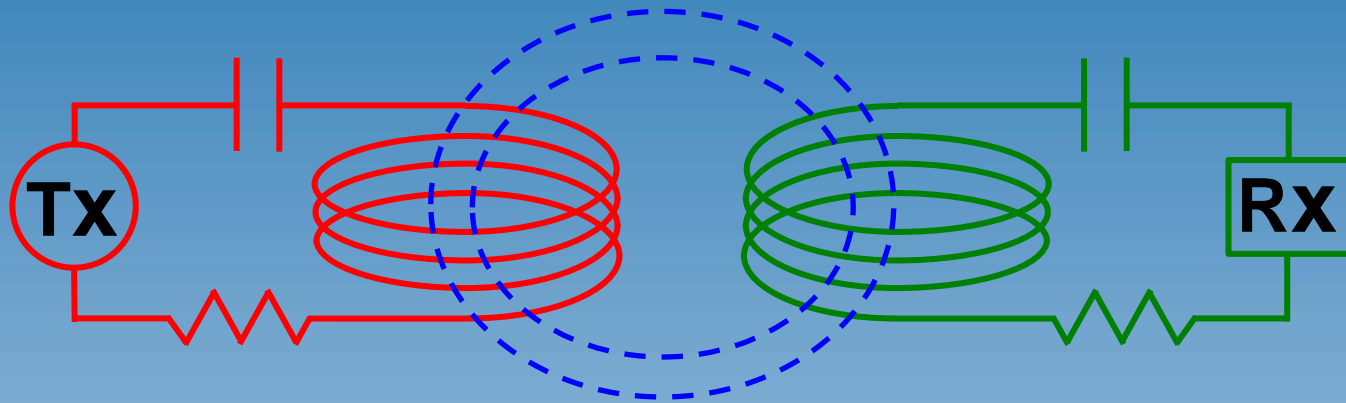


$$Z = \sqrt{R^2 + X_L^2}$$

M-Wave Sensor

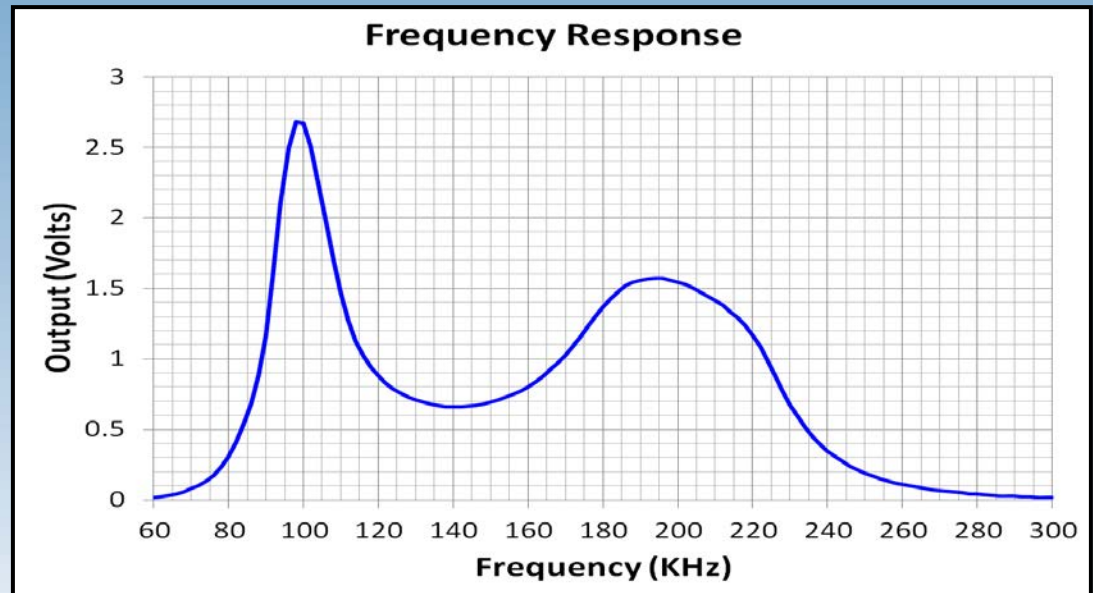


Resonant Transformer

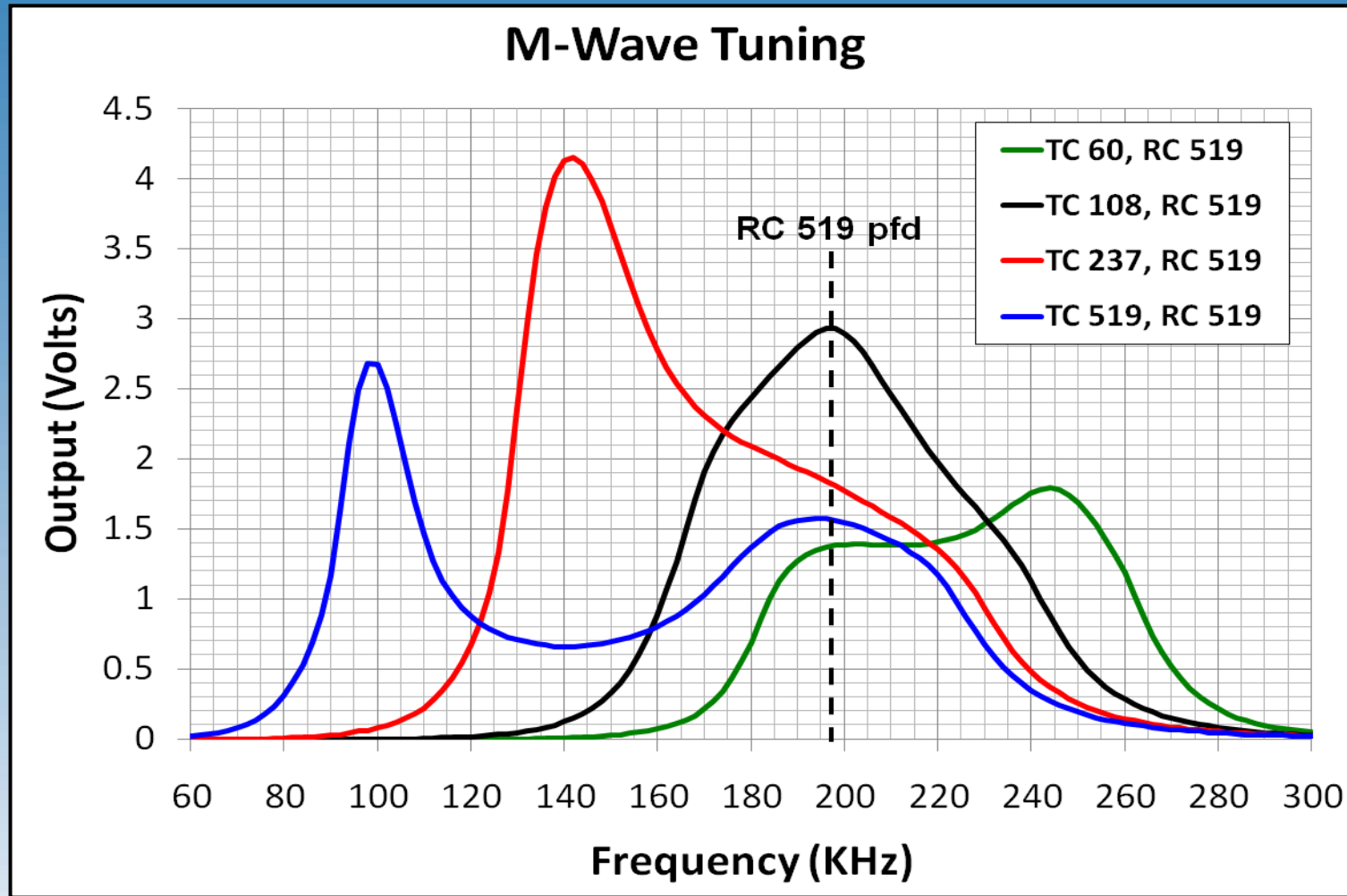


$$f = \frac{1}{2\pi\sqrt{LC}}$$

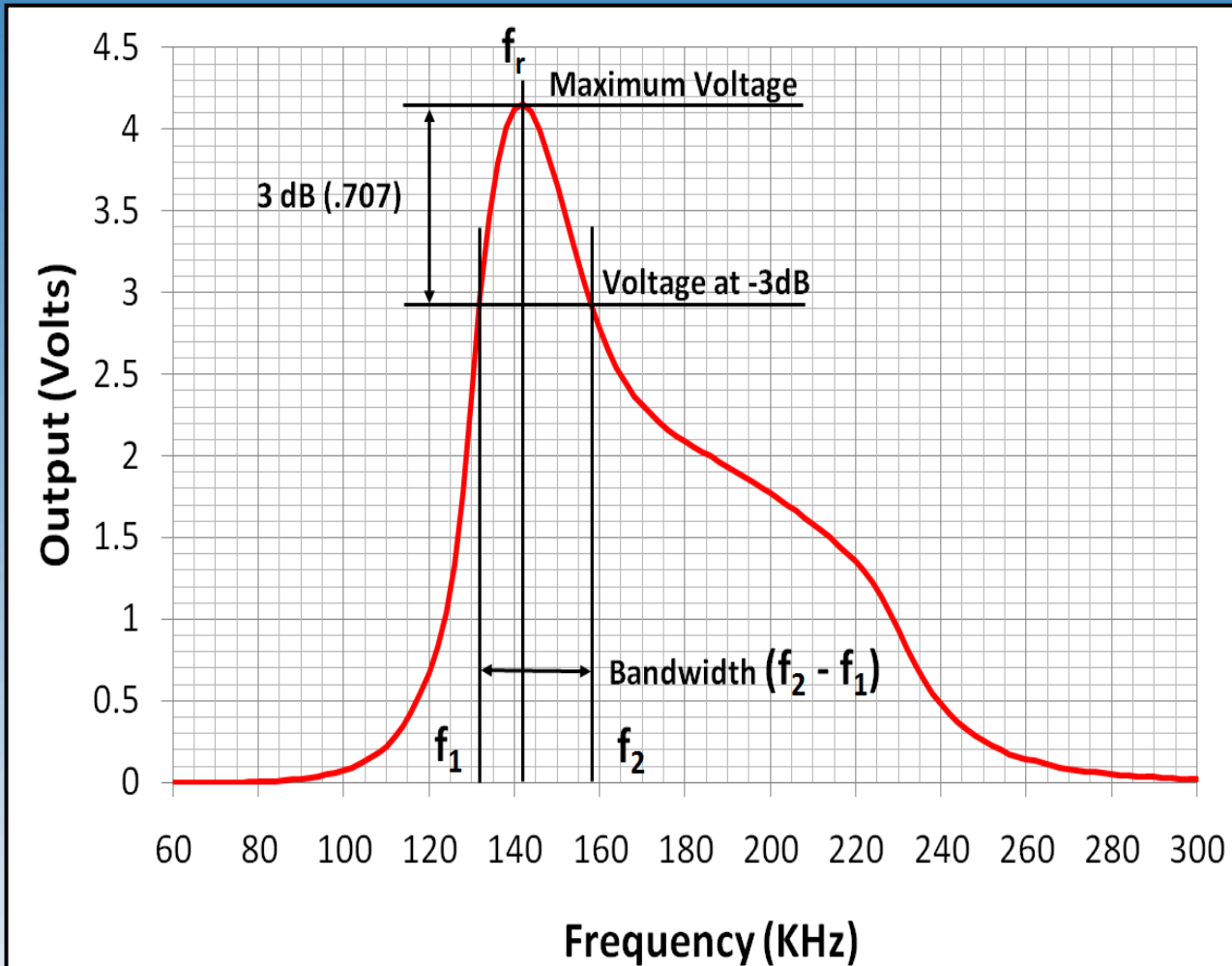
 **-Wave**



Sympathetic Response



Measuring Q

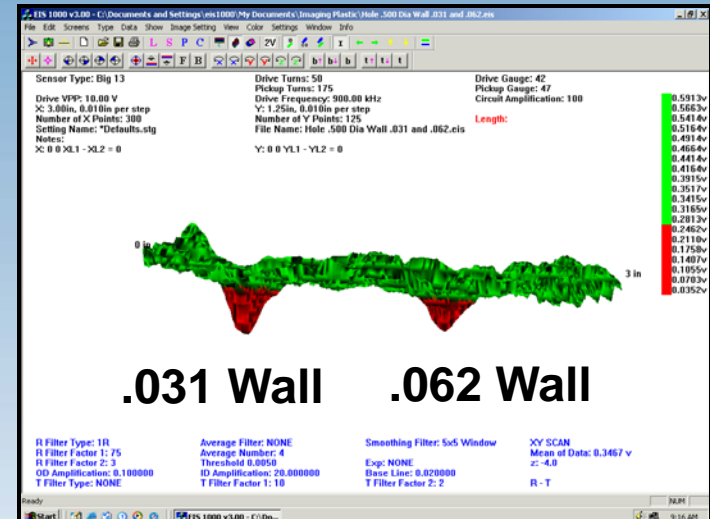
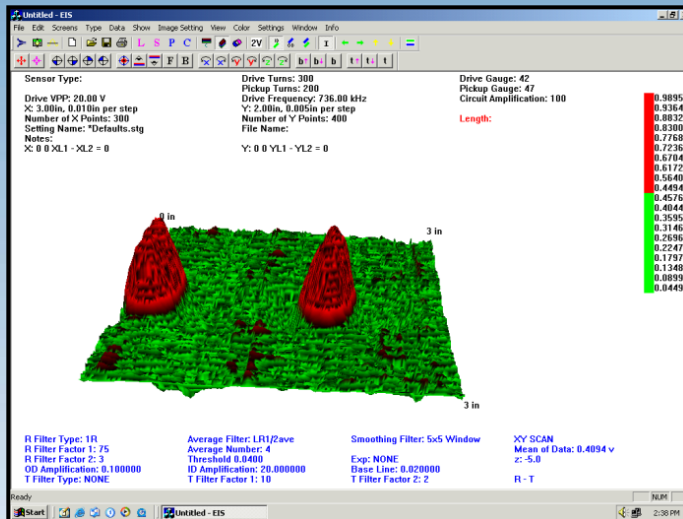
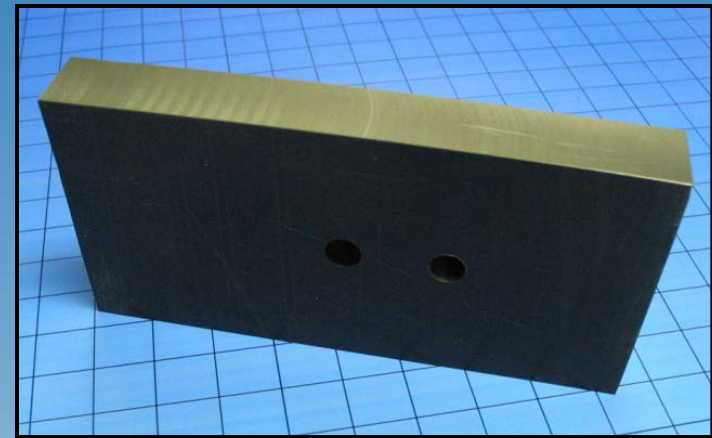
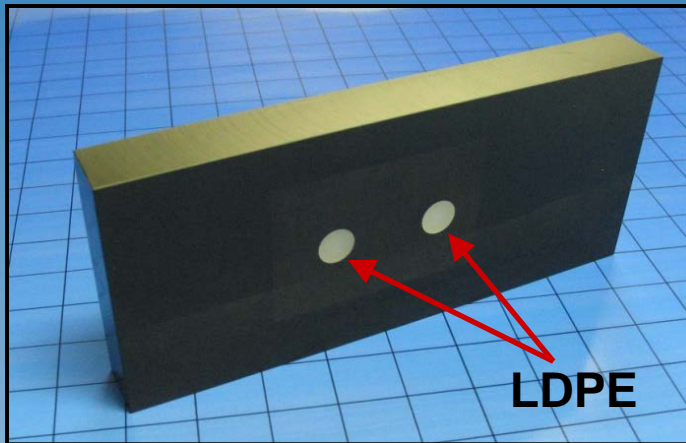


$$Q = \frac{f_r}{f_2 - f_1}$$

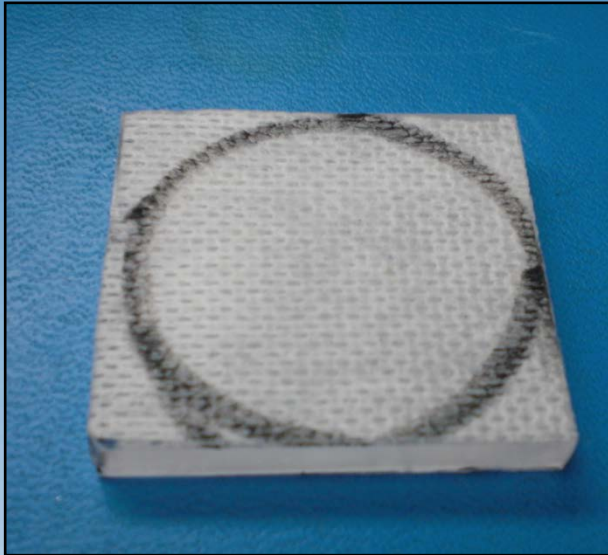
$$Q = \frac{f_r}{\text{Bandwidth}}$$



Imaging Insulators

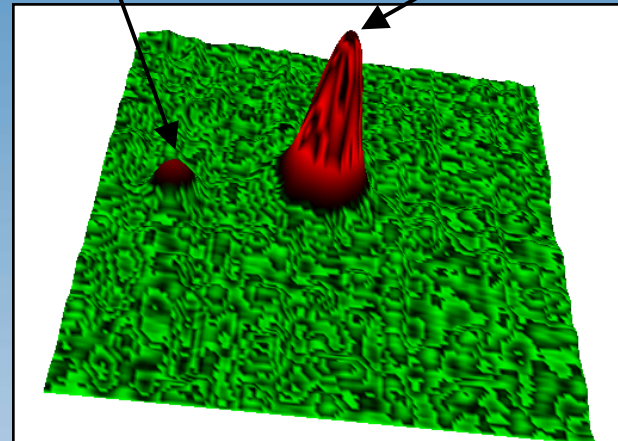


Imaging Plastic



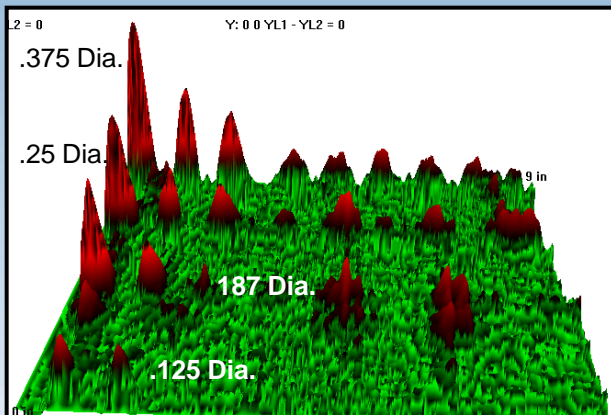
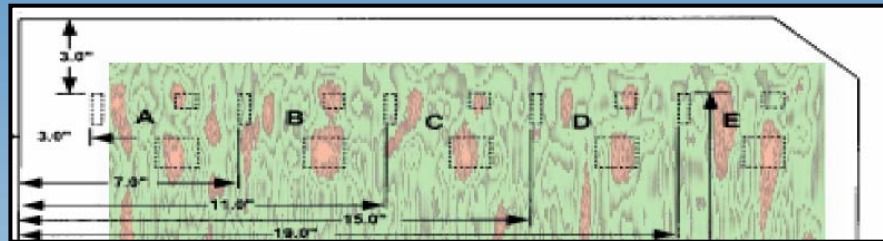
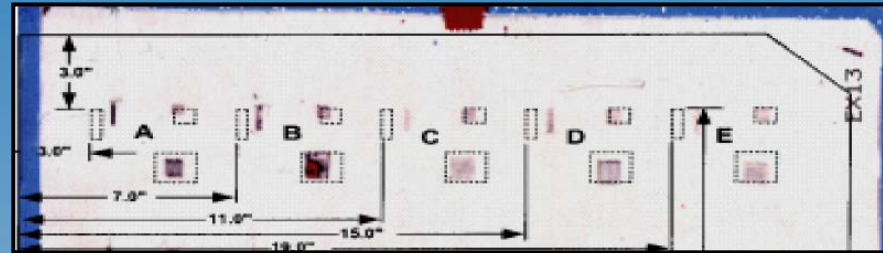
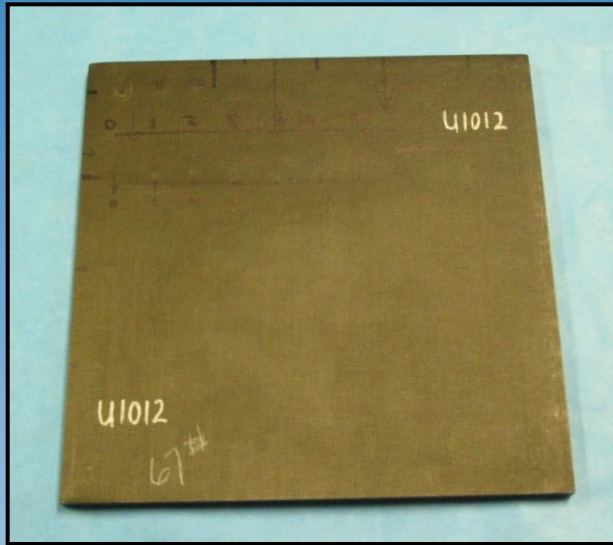
ABS w/ Fabric, BD Medical

.020 Empty Hole **.020 Hole with
.018 Needle**



EXEL Image w/ M-Wave

Imaging Composite



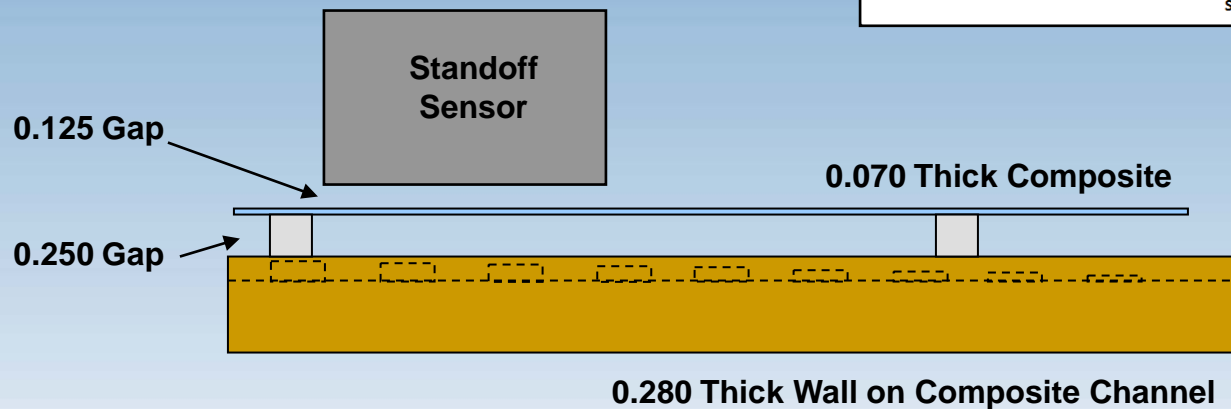
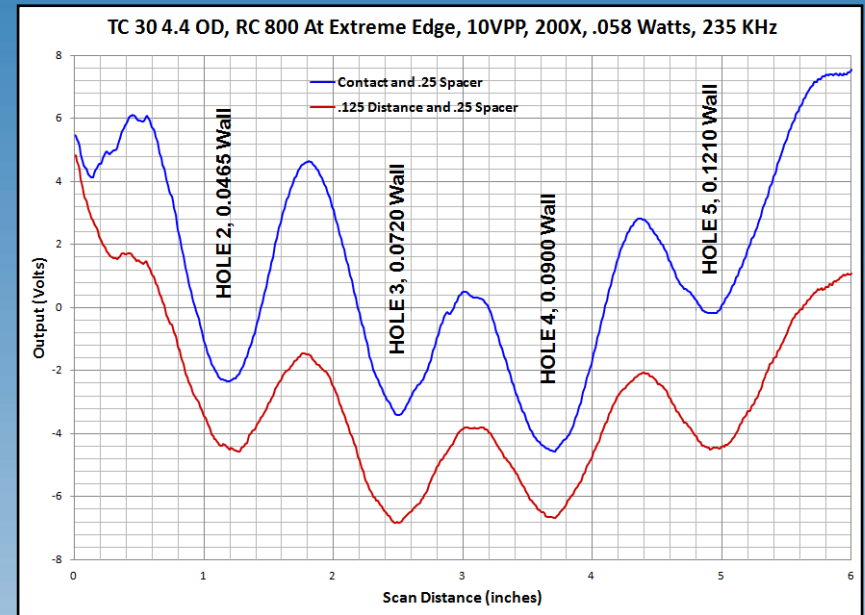
Flaw Group	Backing Type	Flaw Thickness
A	White Backing Paper	.008
B	Transparent Adhesive Backing	.047
C	Brown Backing Paper	.070
D	Yellow Backing Paper	.007
E	Red Backing Paper	.070



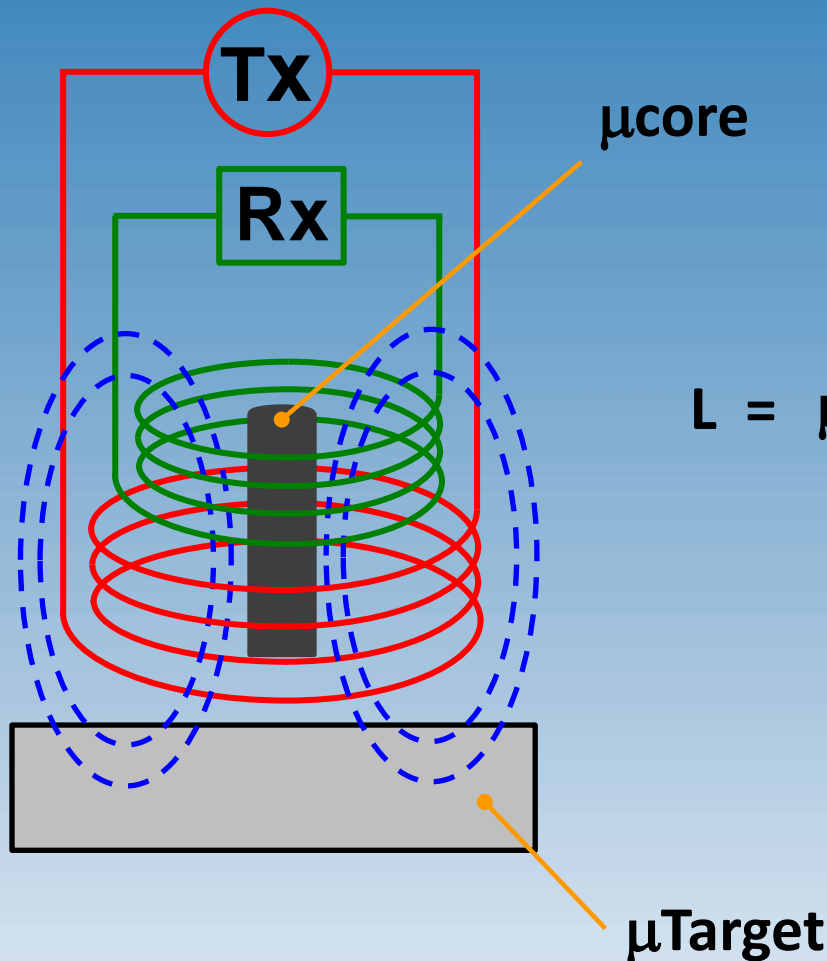
Standoff Multiple Wall Imaging



Stand-Off Sensor with Target at 0.125 Distance



Correcting Image for Distance



$$L = \mu_0 \cdot \mu_{\text{core}} \cdot K \frac{N^2 \cdot A}{\ell}$$

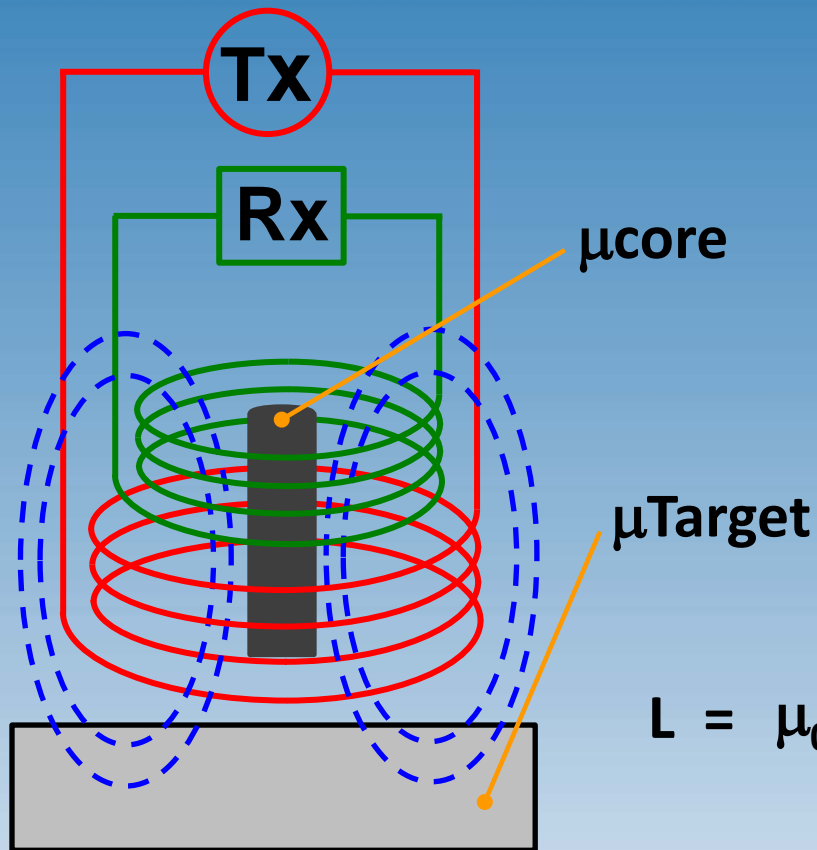
$$L = \mu_0 \cdot \mu_{\text{core}} \cdot \mu_{\text{Target}} \cdot K \frac{N^2 \cdot A}{\ell}$$

* k is coupling coefficient

K is Nagaoka coefficient

μ_0 is 1.256×10^{-6} H/m (vac)

Imaging Insulators



Mutual Inductance

$$M = k \sqrt{L_1 L_2}$$

$$L = \mu_0 \cdot \mu_{\text{core}} \cdot K \frac{N^2 \cdot A}{\ell}$$

$$L = \mu_0 \cdot \mu_{\text{core}} \cdot \mu_{\text{Target}} \cdot K \frac{N^2 \cdot A}{\ell}$$

* k is coupling coefficient

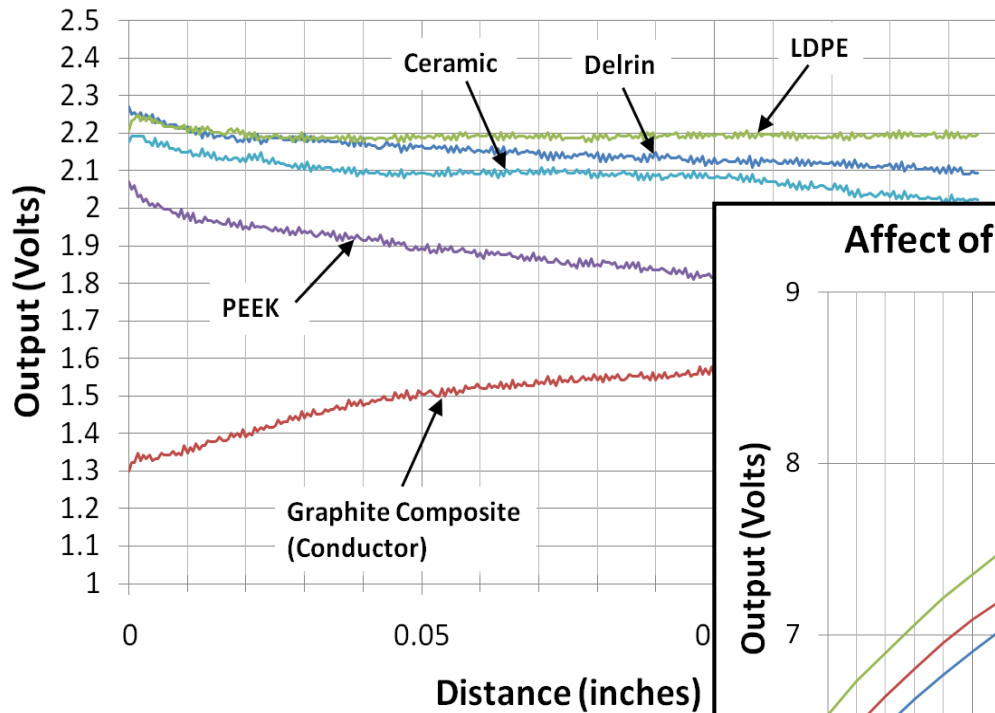
K is Nagaoka coefficient

μ_0 is 1.256×10^{-6} H/m (vac)

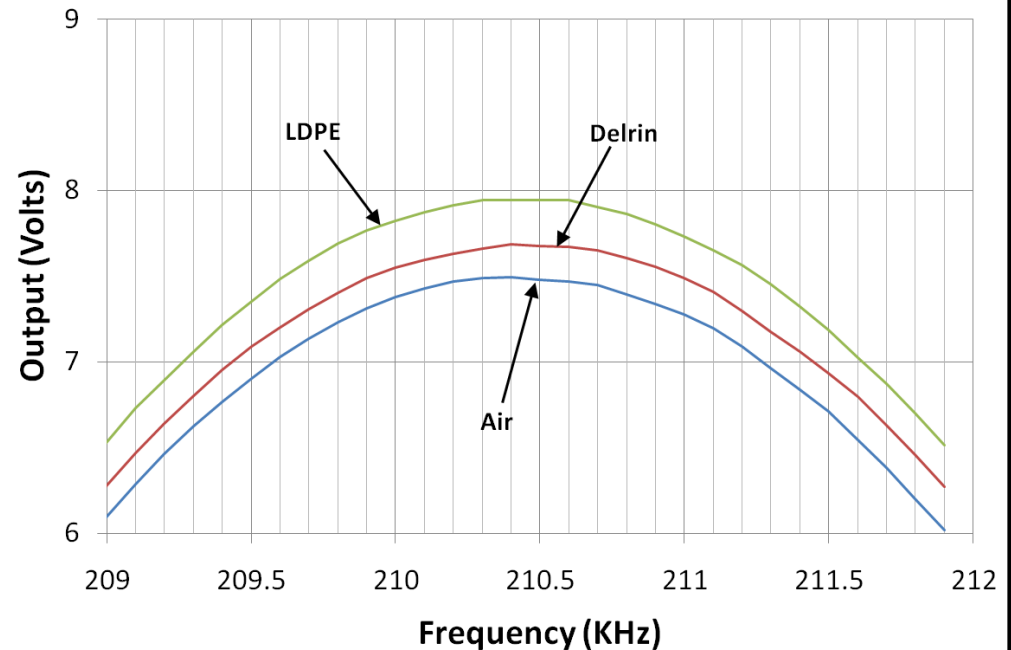


Signal Change from Insulators

Output Over Distance of Insulators



Affect of Non-Conductors on Output (200X)



Permeability vs. Susceptibility

Material	Permeability μ H/m
Steel	8.75×10^{-4}
Aluminum	1.256×10^{-6}
Teflon	1.256×10^{-6}
Nickel	1.25×10^{-6}
Vacuum	1.2566×10^{-6}

Material	Susceptibility χ (mass x 10^{-8})
Aluminum	+0.82
Ammonia	-1.38
Bismuth	-1.70
Copper	-0.107
Hydrogen	-2.49
Silicon	-0.16
Oxygen	+133.6
Water	-0.90

Steel v Teflon
696 :1

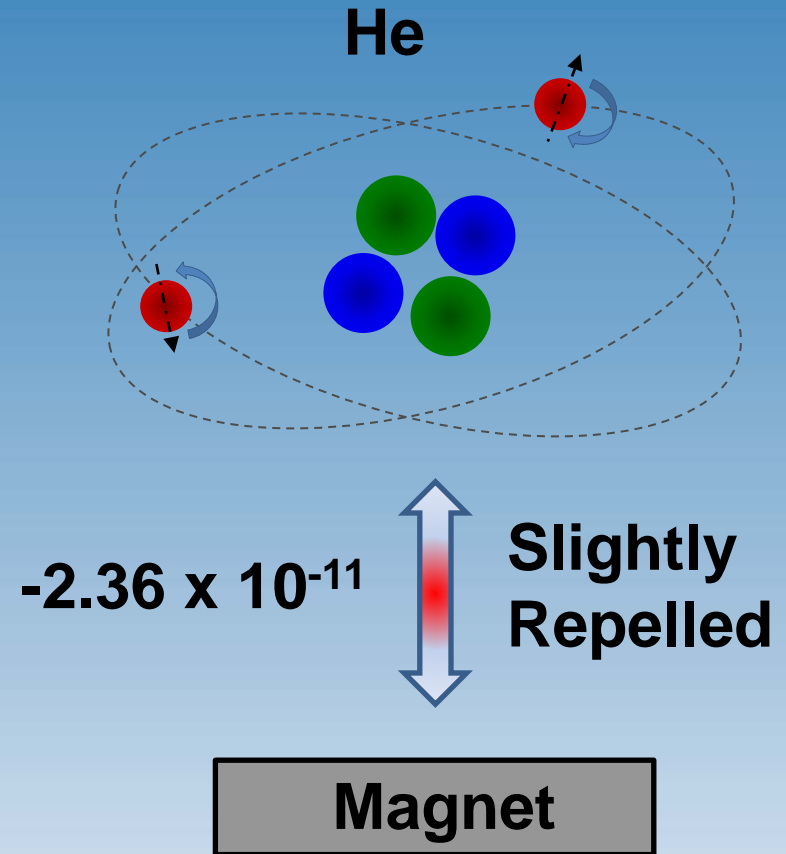
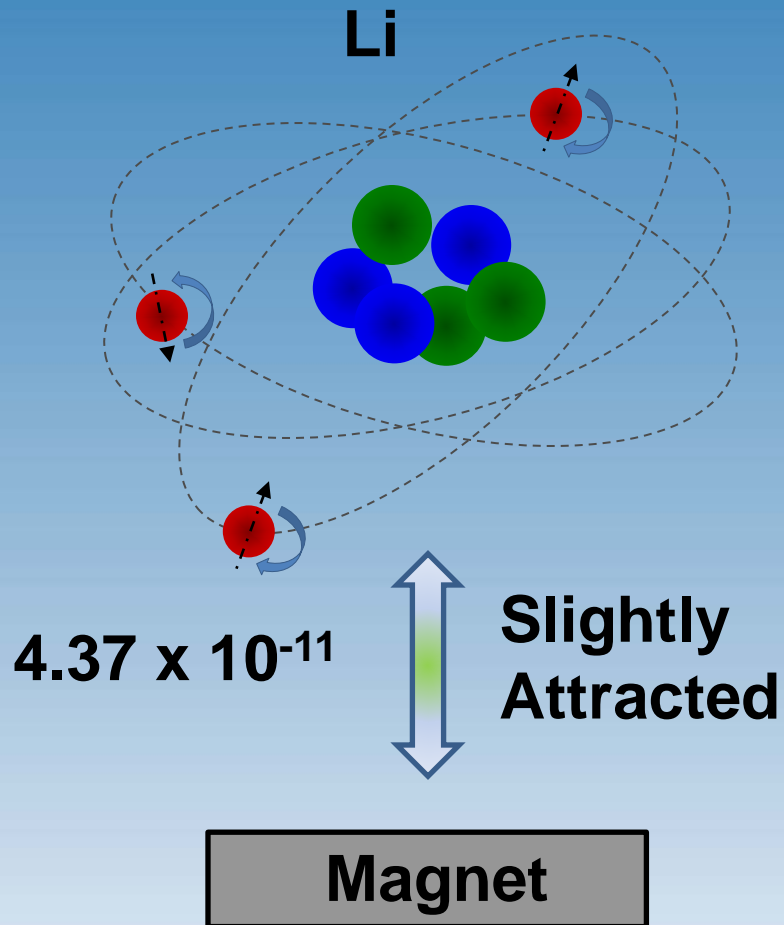
$$\chi = \mu_r - 1$$

$$\mu_r = \frac{\mu}{\mu_0}$$

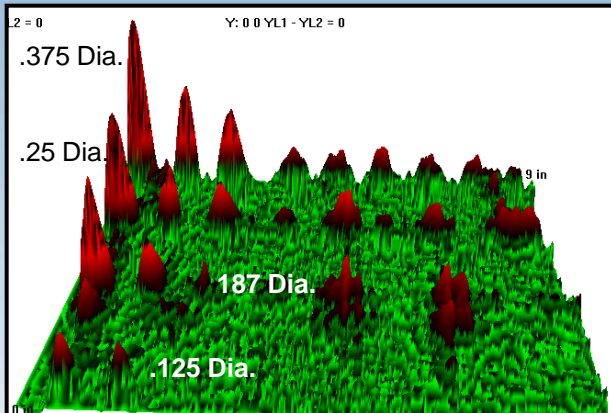
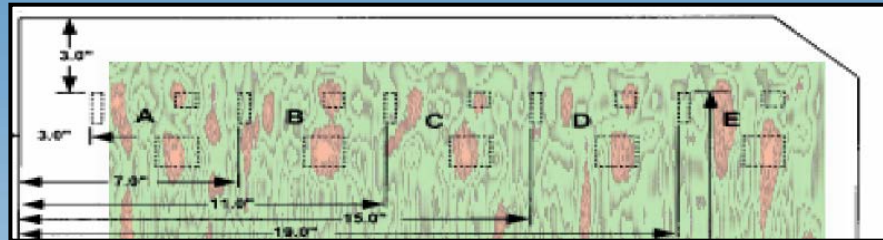
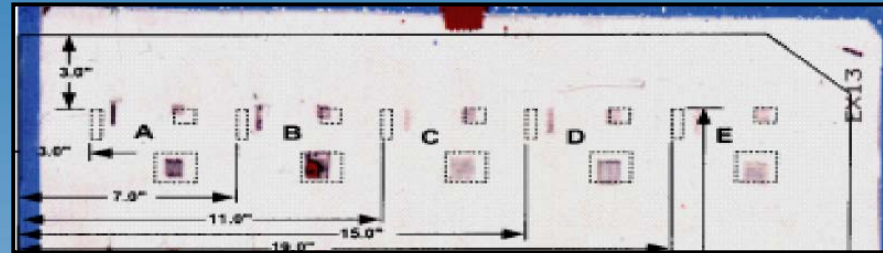
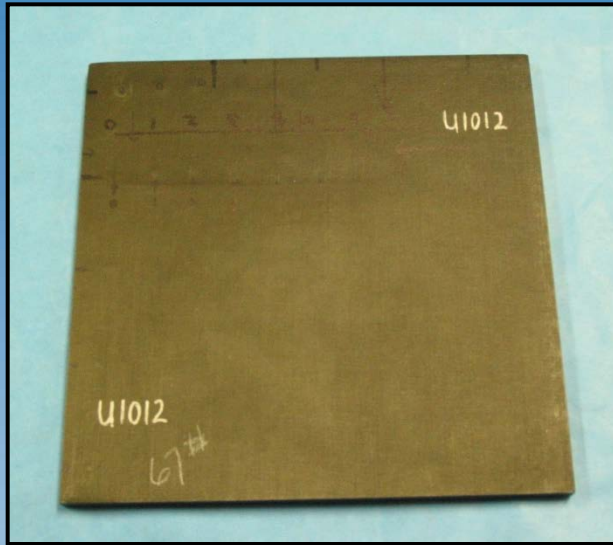
Conductors overwhelm μ



Paramagnetic and Diamagnetic



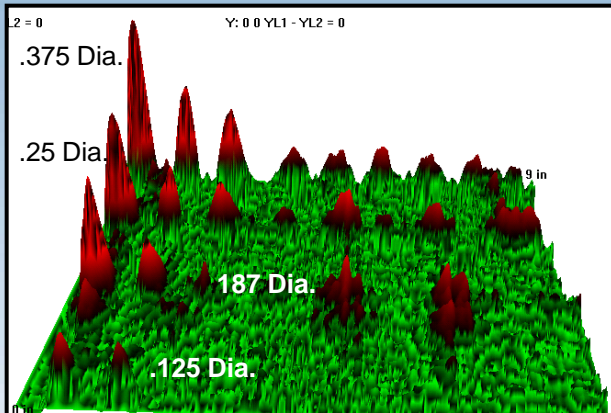
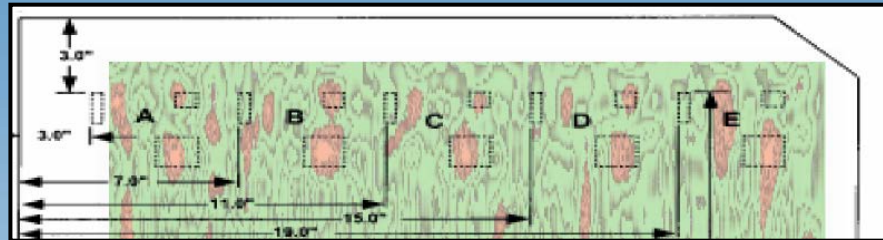
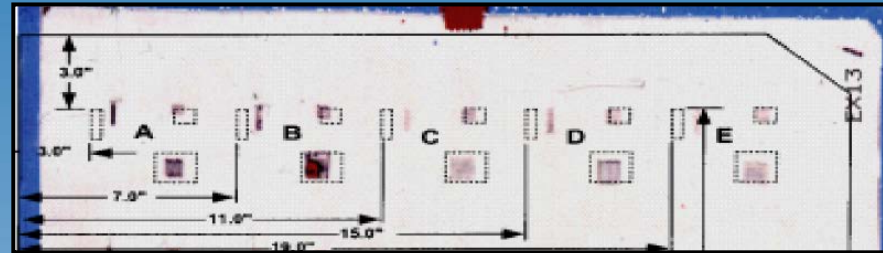
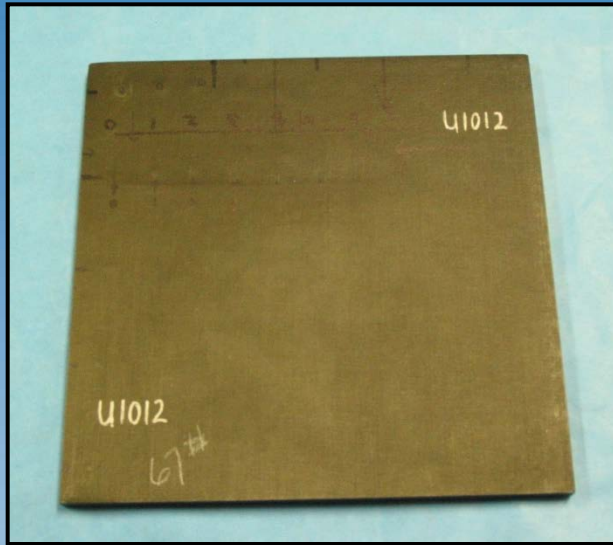
Imaging Composite



Flaw Group	Backing Type	Flaw Thickness
A	White Backing Paper	.008
B	Transparent Adhesive Backing	.047
C	Brown Backing Paper	.070
D	Yellow Backing Paper	.007
E	Red Backing Paper	.070

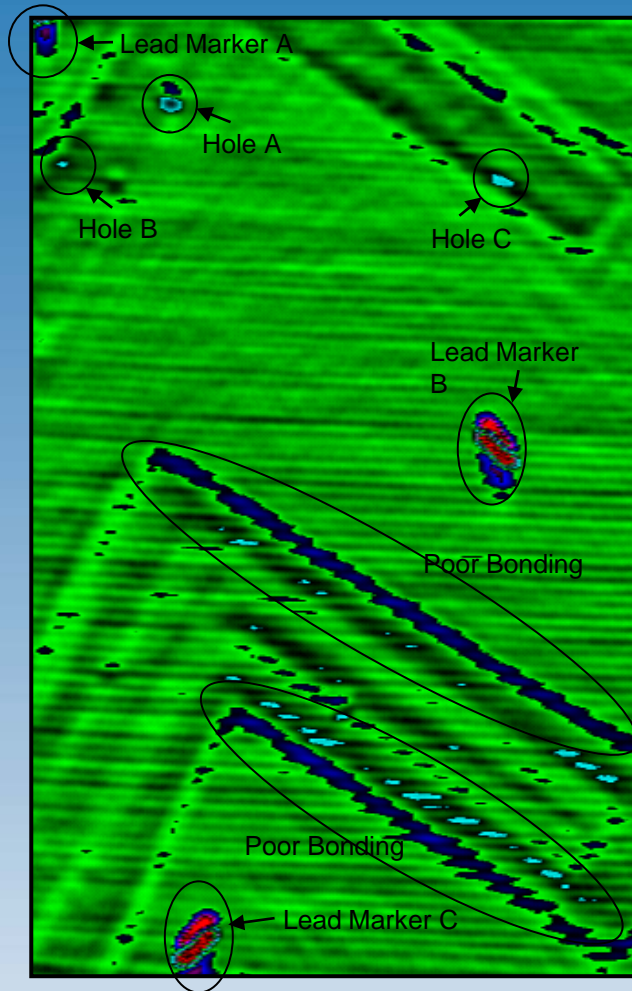
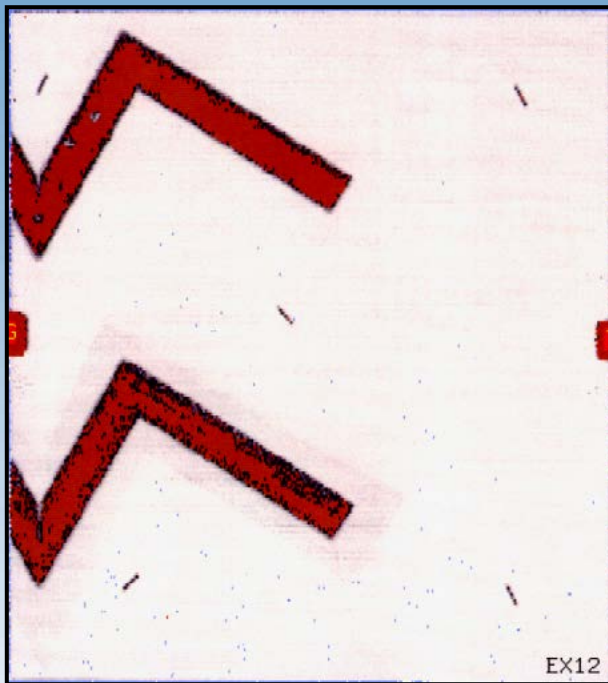
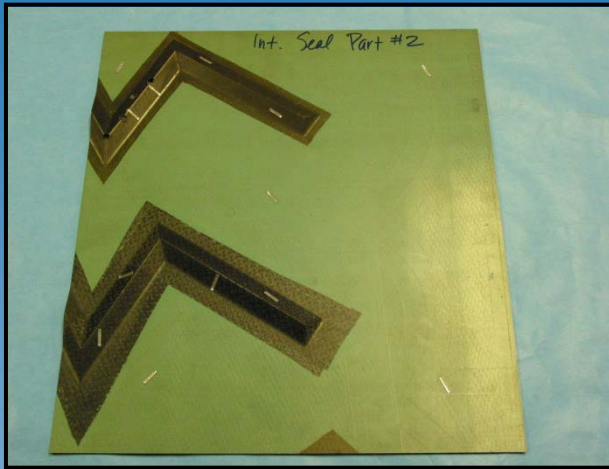


Imaging Composite

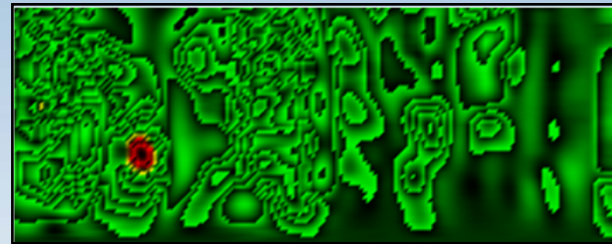
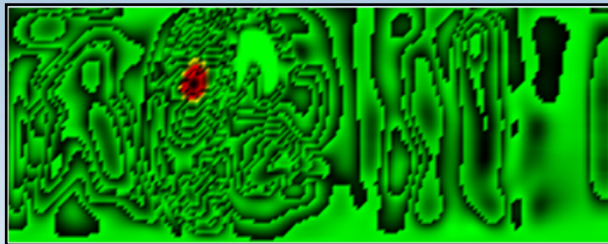
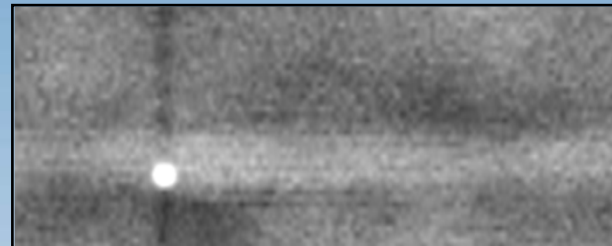


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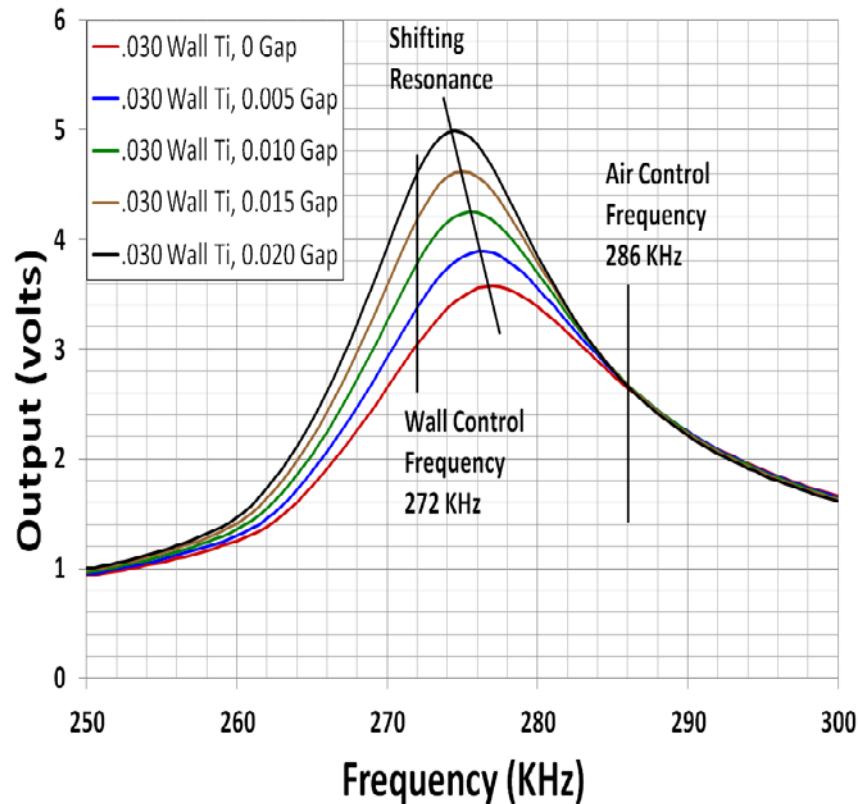


Imaging Tube or Pipe Welds

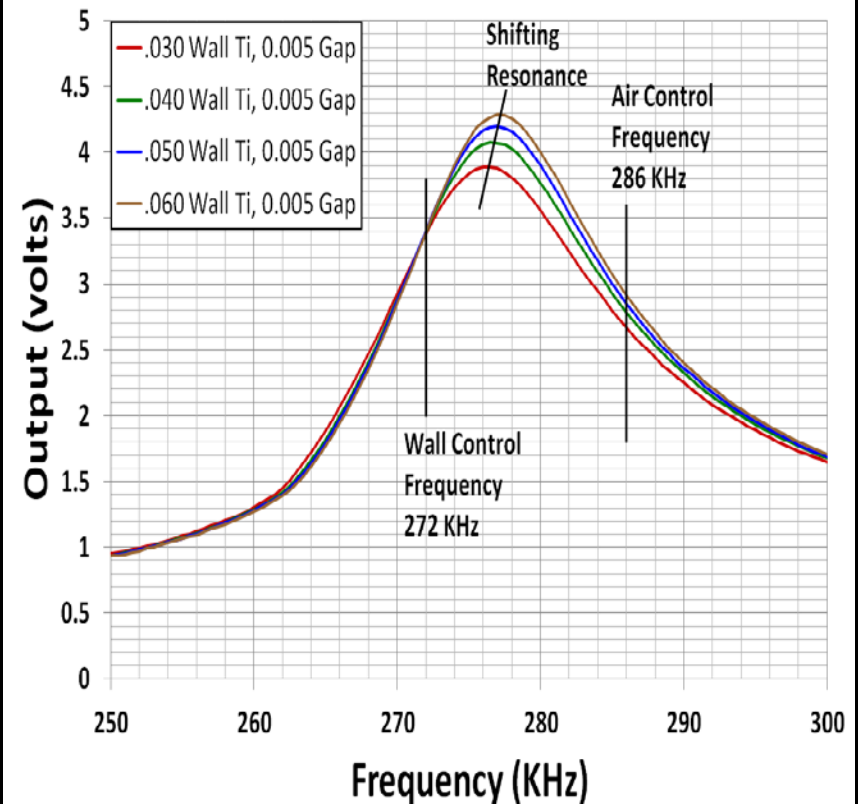


Imaging Orbital Tube Welds

Air Gap Control Frequency



Wall Control Frequency



Imaging an Orbital Weld

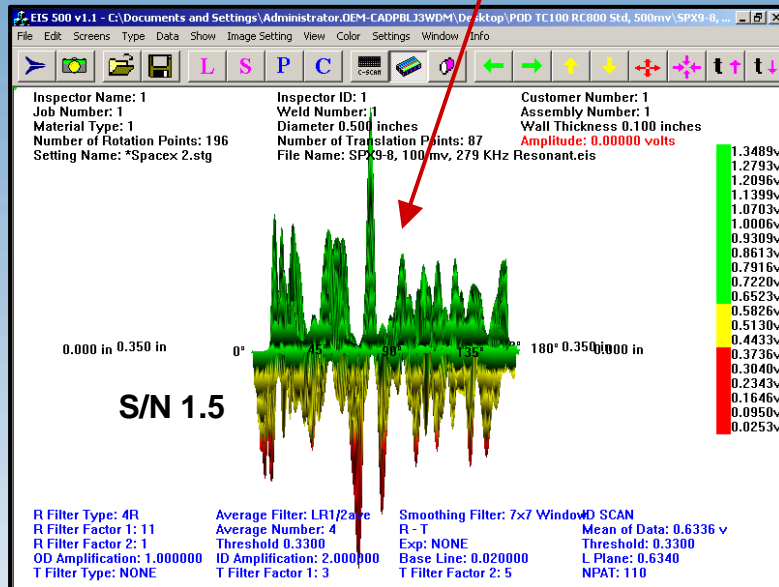
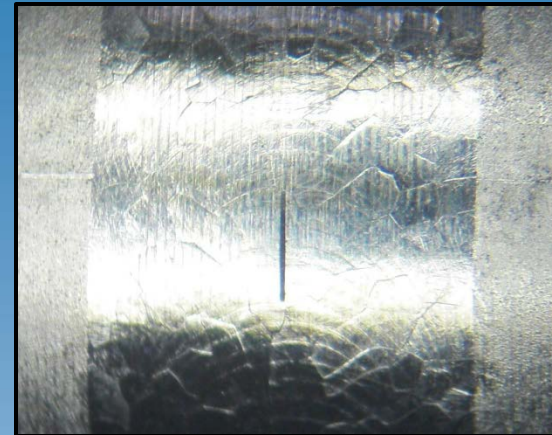
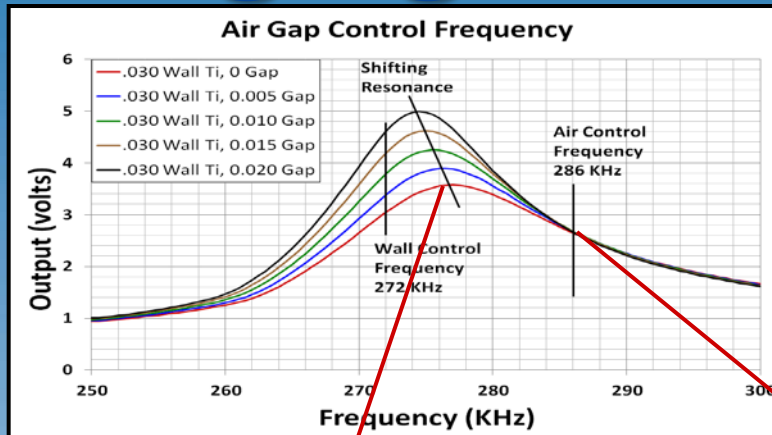


Image at Resonance, 0.050 x 0.018 x 0.003

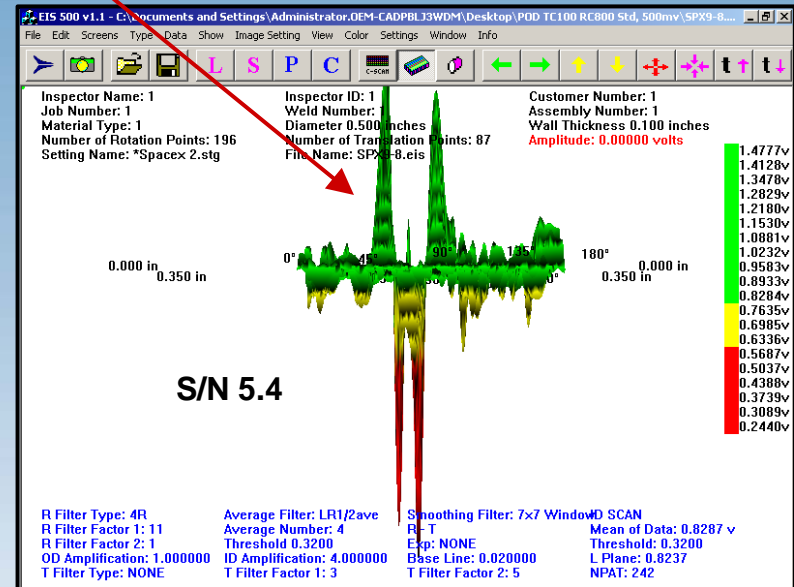
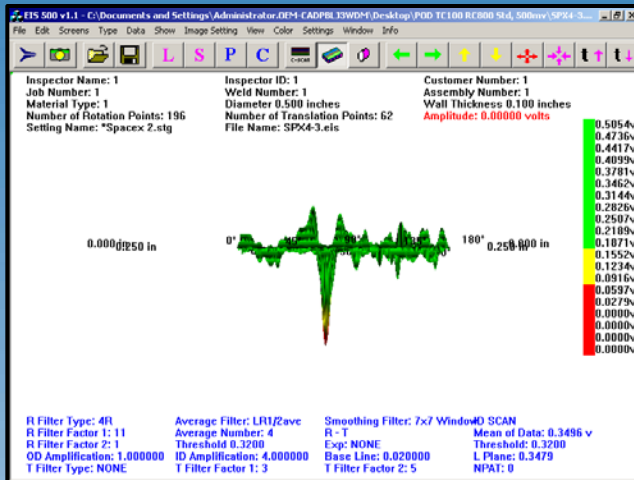


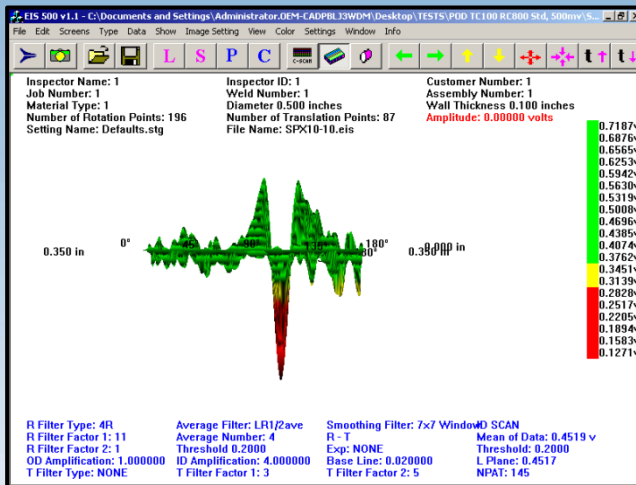
Image at Air Control Frequency, 0.050 x 0.018 x 0.003



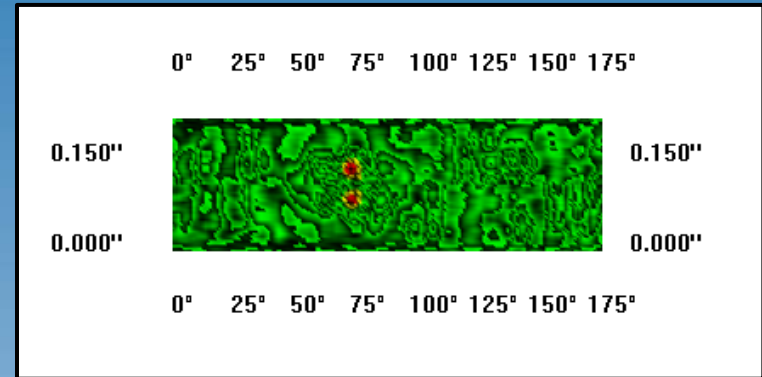
Signal to Noise Ratio



0.030" x 0.014" x 0.003" Flaw, External



0.051" x 0.025" x 0.003" Flaw, Internal,



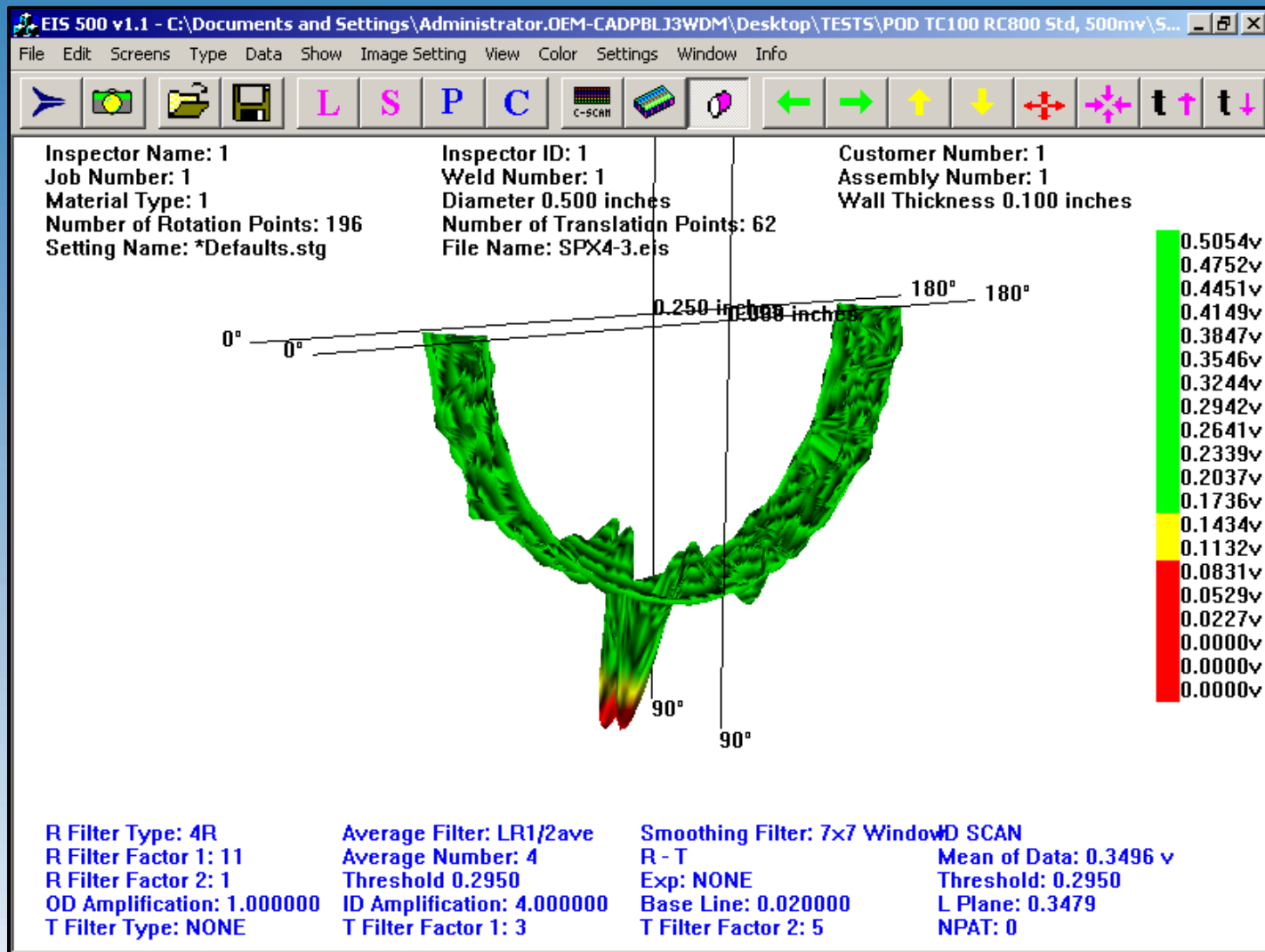
0.030" x 0.014" x 0.003" Top View

Flaw Size	Signal	Noise	S/N
.050 x .018 (od)	.918	.170	5.4
.030 x .014 (od)	.378	.170	2.2
.051 x .025 (id)	.483	.170	2.8

Signal to Noise 3-2.5 Ti



Polar View



0.030" x 0.014" x 0.003" Flaw, External



Robotic Imaging

